

Variable Complexity Optimization of Composite Structures

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This report summarizes the accomplishments and publications of the work done under NASA Grant NAG1-2177. It covers the period of 1/28/99 to 1/27/02

Introduction: The use of several levels of modeling in design has been dubbed *variable complexity modeling*. The work under the grant focused on developing variable complexity modeling strategies with emphasis on response surface techniques. Applications included design of stiffened composite plates for improved damage tolerance, the use of response surfaces for fitting weights obtained by structural optimization, and design against uncertainty using response surface techniques.

Uncertainty and Structural Weight Approximations: In design against uncertainty, it is customary to consider uncertainties due to loads, material properties and geometry. We augment these traditional sources of uncertainty with uncertainty due to the use of response surfaces for approximating structural behavior and due to the errors in the structural optimization used to generate the fitting data. Fuzzy set theory is used to model both the physical uncertainty and the remaining modeling uncertainty.

In addition to characterizing the fitting errors and errors in the structural optimization results, we also explored methods for reducing these errors. Statistical analysis is used to identify so-called outliers in the data. These are points where the structural optimization is likely to have converged to a local minimum or not converged properly. A repair procedure for the data is employed by re-optimization of outlier points by different choice of optimization method and/or using perturbed initial conditions. A paper describing the work has been presented (Ref. 1) and then revised and published (Ref. 2). Follow-up work, with a focus on optimization errors due to convergence criteria has been presented (Ref. 3) and then published (Ref. 4). A similar approach to the effect of multiple starting points on optimization results was presented (Ref. 5). Finally, a procedure for estimating the bias error associated with response surface approximations has been presented (Ref. 6).

Design for Improved Residual Strength: A study of hat-stiffened panel design using low-fidelity and high-fidelity models, previously presented at a conference, was revised and published (Ref. 7). The same idea was then applied, using low-fidelity and high-fidelity models of through-the-thickness crack propagation in stiffened composite panels. The high-fidelity model employs a detailed finite element analysis of the structure with the crack, and the low-fidelity model is based on the stresses at the point in the undamaged structure where the crack will be. A response surface for the ratio of the high-fidelity failure load to the low-fidelity failure load is used to combine the two models for design purposes. This allows the design to proceed based on the inexpensive low-fidelity model, with information from only a handful of high-

fidelity analyses. An example of a plate with two blade stiffeners was used to show the effectiveness of the procedure (Ref. 8). It was then demonstrated that the low fidelity and high fidelity models could also be combined through an equivalent stress constraint. The equivalent stress constraint permits the usage of commonly available structural optimization packages (Ref. 9). Reference 8 and 9 were combined to a single paper accepted for publication in Structural Optimization (Ref. 10). Finally, the idea of uncertainty in weight equations was applied to a weight equation for stiffened panels designed for damage tolerance (Ref. 11).

Derivative-based Response Surface Techniques: Response surface techniques are limited to a modest number of design variables, typically under 20. Since the research performed under the grant has demonstrated many advantages associated with the use of response surfaces, we are investigating the use of derivatives to extend the range of application of response surface techniques. Derivatives are often available at a fraction of the cost of function evaluations, and for these cases, the use of derivatives could be beneficial. Unfortunately, response surface techniques were originally developed for experimental optimization, where derivatives are normally not available. Consequently, there is very little theory for response surfaces incorporating derivatives. Preliminary work on developing such theory has been initiated (Refs. 12, 13). It shows that while derivatives can help improve the accuracy of response surfaces, it is important to develop the theory that will allow us to use them efficiently.

Reliability-based design of launch vehicles: Reliability based optimization is very expensive, because reliability calculations typically require hundreds or thousands of analyses. In addition, because probability estimates are noisy, gradient based optimization algorithms perform poorly for such problems. Response surface techniques can help reduce the cost and filter out the noise. A paper on different options for the use of response surface techniques has been presented (Ref. 14). It showed that response surfaces based on both random variables and design variables simultaneously are most efficient.

A study of reliability based design of a composite panel designed to withstand cryogenic cooling without leaking fuel was conducted (Ref. 15). The study showed that microcracking is a serious problem that may lead to substantial weight penalties. Limiting variability in material properties, particularly those that relate to expansion and strength in the direction perpendicular to the fibers, appears to be critical (Refs. 16,17).

Analytical-experimental correlation of panel designed with genetic algorithms: A paper describing the analytical-experimental correlation for a panel designed with genetic algorithms was published (Ref. 18). One goal of the paper is to explore the impact of the simple analytical models used in the design. The second objective is to use detailed models for understanding the evolution of structural response in the experiments.

Miscellaneous: Results of carbon fiber composite I-section compression tests partially sponsored by the grant were compared with the results by analysis and accepted for publication (Refs. 19, 20). A survey paper of methods for structural sensitivity computations was presented (Ref. 21). A paper on the use of response surface techniques for design with fuzzy sets was published (Ref. 22). A paper on comparison of polynomial response surfaces and neural nets for design optimization was presented (Ref. 23).

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